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Introduction

Soil degradation resulting from industrial farming activities is ("Dust-Bowl syndrome"), with regard to its causes and effect, currently one of the most important environmental problems (WBGU 1994). Poor take up of recommended agricultural management techniques led, especially in sensitive semi-arid ecosystems, to numerous ecological as well as socio-economical problems. This resulted in an irreversible soil degradation, leading to declines in yield of varying severity, or even total loss. Consequently, many farmers had to give up their activities and vast areas suffered a major population loss.

The ecological risk of intensive agricultural land use in semi-arid areas has so far been studied in detail in the Great Plains of North America. During the first half of the 20th century an intensive, industrial agriculture (black fallow, mono-cultural systems, deep ploughing) combined with regularly occurring droughts, led to wind erosion and considerable soil degradation (Späth 1980). Various investigations have been undertaken of this "Dust Bowl" condition (Hudson 1987; Morgan 1986; Fryrear 1990). These investigations were focused on process analyses and the development of erosion prevention systems tailored to the specific site conditions, as well as methodological aspects of dry farming systems. In contrast, so far very little is known about reclamation activities in the former Soviet Union. This applies the to Russian literature especially with respect the to areas outside Russia itself.

The first scientific information gathered about forms, intensity, dimensions and effects of site reclamation was made available beyond the borders of the former Soviet Union primarily due to the efforts of Eule (1962), Breburda (1965) and Wein (1980, 1983). According to these authors site reclamation was affected by the need to supply the population with grain, an extremely difficult task in the USSR after World War II, because of the shortfall in supply. Average grain yield was 18 z ha^{-1}; the overall need of 32 million t more than the country's total production of 31 million t (Breshnew 1978, p. 24). The first step was to look at the intensification of grain cultivation in the areas already available at that time. Yet, the demand for mineral fertilizers could not be met by the extremely war-weakened industry (Georgiev 1955). Furthermore, compensation was required for former classical "corn belt" in the Ukraine. Despite the large territory of the former Soviet Union, there is only a relatively narrow belt suitable for grain production between the vast permafrost areas to the north and the rather dry steppe to the south.

To solve this conflict, the leadership of the former USSR Communist Party decided on the expansion of the grain acreage in arid regions of the country in 1954 (Wein 1980). This activity became known as the "reclamation campaign" ("tselina"). As early as April 1954, only two months after the decision for the reclamation campaign, ploughing and seeding activities started. About 17 million ha of previously virgin steppe were tilled in the first year of the reclamation campaign (Georgiev 1955, p. 3). The expansion of the acreage continued in the steppes and dry steppes until 1960. During this time, a total of 41.8 million ha of new acreage were ploughed in southern Russia and Kazakhstan (Eule 1962, p. 115; Wein 1983, p. 9) *(Tab. 1)*. The largest part of reclamation sites, accounting for 25.5 million ha, was in Kazakhstan (Wein 1983, p. 7).

Reclamation district	Area (in Mio. ha)
Kazakhstan	25,5
Volga Region	1,5
Ural	4,5
Western Siberia	6,2
Eastern Siberia	4,2
Total Former USSR	41,9

Tab. 1: Distribution of the reclamation sites in the former USSR
Source: Eule 1962, p. 115

The target area of the reclamation campaign was the Eurasian steppe belt in an area with 300 mm precipitation p. a. with characteristic soil types such as southern Chernozems and Kastanozems (*Map 1, see supplement A*) (Rostankowski 1979). These dry steppe areas are not only known for their variability of precipitation, but also for the lack of it. These high continental steppes receive precipitation mainly as convective rain during summer (GUGS 1977). During the growing season of the main crop, spring wheat, only 140 mm of precipitation fall on the long-term average (Rostankowski 1979, p. 85). However, due to the high temperatures in summer evaporation far exceeds precipitation (GUGS 1977).

These basic agro-meteorological data already point to the great risk of droughts and thus yield reduction. Precipitation amounts of about 300 mm p. a. have been defined as drought in the Great Plains (Späth 1980, p. 107), but these precipitation values are only the long-term average in the site reclamation areas of the former USSR.

A highly predictable risk was posed by wind erosion. Devastating dust storms had already affected the reclaimed areas in 1956 (Kostrovski 1959). Every year 187,500 ha of reclaimed land were devastated by wind erosion, prohibiting further agricultural cultivation of these sites. Up to 1963 13 million ha, equivalent to more than 30 % of the complete reclamation sites, were degraded by wind erosion, resulting in lower soil productivity and yields (Wein 1983, p. 11).

Since then, very few investigations have been undertaken concerning the soil degradation and its later consequences. Details are hard to find even in the Russian literature. There is an urgent need for analyses and evaluation of the causes and effects, from both a geo-ecological as well as socio-economic point of view, including independent data acquisition obtained by field studies and a literature review. Therefore, an independent field study that is supported by the DFG (German Research Foundation) builds on existing cooperation with Russian colleagues. Here we report on the main results achieved in the Kulundasteppe during this project.

Natural and social characteristics of the study area

The Kulundasteppe of the Altaj region represents a characteristic part of the southwest Siberian steppe belt between the dominantly deciduous woodland zone bordering the boreal coniferous forest zone and the south-east bordering the mountain area (*Map 2, see supplement B*).

Characteristics for the semi-arid and high continental climate are great temperature amplitudes (-40 °C in winter and +35 °C in the summer) as well as a short growing season (Atlas Altajskovo kraja 1978, pp. 77 - 80). The precipitation is, on average, only 250 - 400 mm p. a. (GUGS 1977, p. 23) Typically, there is also a high temporal and spatial variability. During the last few years, total annual precipitation revealed especially great fluctuations with 3 to 6 years periods of drought (*Fig. 5*, Chapter "Feedback of agricultural production").

Characteristically, convective heavy rain occurs in the investigation region, bringing up to 30 - 70 mm precipitation over a short period (GUGS 1977, p. 46). The available water that would be needed evaporates relatively fast and/or can lead to erosion as a result of heavy surface runoff.

Soil types in the study region are sharply differentiated from south-east to north-west, as well as a steady south-westerly increase in altitude. Southern Chernozems, bordering the typical Chernozems, are characterized by lower humus content in the A-horizon and generally shallower depth. Compared to the nearby open forest steppe, precipitation and especially snowfalls, are generally reduced in the central steppe, leading to a lower biomass production and hence humus accumulation potential. This typical steppe is pedologically characterized by dark Kastanozems. Along with a further precipitation decline (approximately starting from 80 ° longitude) bright Kastanozems appear in the central Kulundasteppe, with humus contents ≤ 4 % in the upper soil layer (Gorschenin 1955, p. 34).

A further sequence of soil types is found to the south-east of the central dry steppe, where a catena can be found exhibiting bright to dark Kastanozems, along southern margin along with typical Chernozems to Cambisols and finally Podzoluvisols. This sequence is a response to the precipitation gradient caused by the Altai Mountains.

In addition the edaphic conditions soil fauna is another essential factor influencing the steppe eco-system. Due to summer dryness and especially to winter cold, species like suslik (Citellus suslicus), hamster and ground-squirrel, as well as earthworms, are found in the deeper soil layers causing a distinctive biotic disturbance in the study region (Gorschenin 1955; Tanasienko 1992). These activities enhance humus accumulation within the A-horizon and prevent decalcification. Solonchaks and Solonetz are found mainly in basins, often near enclosed lakes.

The study is centered around the German National Rayon (*Map 2*). About 6,000 inhabitants of German origin live here, close to the Kazakhstan border (Blickle 1997, p. 23). The total number of the region's inhabitants was 20,700 in 1996 (Blickle 1997, p. 12). These people originally came from the Volga region. Their deportation took place during World War II when Stalin forced them to move. At the behest of the German Federal Ministry of the Interior (BMI), the German Society for Technical Cooperation (GTZ) is trying to diversify economic activity and thus offer a future which will reverse the rising emigration from the region. The agricultural production plays an essential role, but so far there is hardly any information about the key natural and other factors which will determine its viability.

Methodology

To investigate soil degradation processes resulting from the last 50 years of tillage activities, it was decided to make a comparison between virgin and ploughed sites. The basic condition for this research scheme was that the soil profiles be as similar as possible, thus guaranteeing comparable soil, genetic, climatic and geomorphologic conditions. Therefore, the relatively little differentiated northern and central part of the Kulundasteppe was chosen.

As far as wind erosion was concerned, two sites (Slavgorod/test area of German National Rayon) with overlying A-horizons were used as references.

The evidence that these reference sites have not been tilled before was determined botanically by the occurrence of *stipa pennata*. Furthermore, in contrast to the reference variants, the profiles offered a very clear Ap limit, as was shown on ploughed Kastanozems and partially at Chernozems. In order to ensure the virgin character of the reference profiles, an additional method using the tracer element Caesium 137 was used. Experience from pilot-investigations were helpful because they revealed that the predominant share of the Russian radionuclide contamination was deposited in the lee of the former Soviet atomic bomb test area at Semipalatinsk before the site reclamation campaign (Meinel 1998). Therefore, we could assume the soil was untouched and virgin (reference site) if a distinct decrease of the Caesium content within soil profile was found.

Additional results were obtained using the half-life of Caesium, confirming the form and the extent of soil erosion on the thickness and development of single horizons. Intensive wind erosion led to the complete loss of this tracer at some locations.

Spatial dimension of the reclamation activities and current forms of agriculture

The central Kulundasteppe was hardly cultivated before the reclamation campaign except for use as pasture and some small-scale agrarian activities near the few settlements (Orlovski 1955). Traditionally, it was usual to cultivate wheat in areas with a minimum of 400 mm precipitation p. a. (Kostrovski 1959, p. 37). As a result of the introduction of the "tselina" in 1954, this former limit for grain production was now ignored. The natural conditions of the Kulundasteppe indicated that higher yields were to be expected for more than just a short time period. Southern Chernozems and relatively high precipitation led to expectations of constantly higher yields, especially in the northern steppe region.

More than 2.3 million ha of arable land were gained during the years 1954/55 in the Altaj-territory (Orlovski 1955, p. 67), an increase of 150 % on the former area. A summary of the distribution of the area of increase in the investigation area is given in *Map 3* (*see supplement B*).

As shown in *Map 2*, the increase in arable land was greatest in the dryer parts of the Kulundasteppe. Site reclamation activities took three forms:

1. The main part was the cultivation of the area of dark and light Kastanozems in the central steppe region, that neighbour the southern Chernozems, the Districts (Rayon) Slavgorodskij, Kulundinskij, Tabunskij, Kljuchevskij, Mikhajlovskij and Uglovskoje. Yearly precipitation amounts were far below the 400 mm limit and, in some parts of this area, did not even reach 250 mm (Kostrovski 1959, p. 38).
2. The reclamation campaign not only included natural steppe sites but also old fallow sites that had been cultivated. These areas were attached to former settlements, which had been abandoned before World War II as yields declined due to the incidence of droughts (oral statement by the Kolkhoz chairman). Most of these settlements were abandoned between 1932 and 1936 (Central Archives 1964). Furthermore, the fields around the existing settlements were redistributed as part of the reclamation campaign. The aim of these activities was the establishment of larger field units, on average of 100 ha each. Also, the general reorientation of the fields was based on the prevailing wind direction. Since then, all fields in the Kulundasteppe are rectangular in shape and oriented at right angles to the main wind direction (SW), i. e. northwest to southeast.
3. In order to extend the cultivated area, sites with gradients of up to 10 % were tilled for the first time during the reclamation campaign as well. The reason for this measure was on the one hand, the overall extension of the cultivated areas as demanded by the central national plan and, on the other hand, the availability of modern technology which now allowed steeper sites to be cultivated. (Demin 1993). The cultivated upper slopes were also reformed into field units of about 40 ha. These forms of agricultural cultivation were carried out particularly in the south eastern border area of the Kulundasteppe, in the zone of transition to the Altai.

During the first years of the reclamation campaign mainly traditional technology was used which had already been proved in the classic Chernozem areas. This included the preparation of the soil for sowing by ploughing followed by harrowing (Tanasienko 1992). In order to meet the demand for higher wheat production, spring wheat was cultivated continuously on the new sites for a period of four years. As a consequence, a series of serious wind erosion events were followed by a decline in yields. Therefore, the introduction of protective measures against erosion was necessary. These included planting windbreaks, the introduction of crop rotation and fallow fields, as well as the application of the Malzev-method. The latter replaces the ploughing procedure by a flat cut so that the substrate is not turned upside down but only loosened (Baraev 1976). The method ensures that weed roots are actually destroyed due to the "destruction of capillarity". In contrast to the traditional method, this approach succeeded because it ensured that the roots dried out completely (Tansienko 1992). In addition, there were further positive effects through minimizing transpiration and, hence, the prevention of wind erosion, by leaving the stubble in the field. Ultimately, the necessary widespread use of this erosion prevention method was not achieved and traditional ploughing still predominated. As of today the substrate on fields in the dry central part of the Kulundasteppe is turned upside down, often to a depth of about 25 cm. The further soil preparation processing is then carried out by the use of cultipackers and cultivators (Malzev-method). Using this method a combination of traditional and minimal tillage is applied.

During the phase of the Intensification (1965 to 1980) crop rotations were recommended and introduced, including the adoption of fallow years. Generally, such established forms of land cultivation revealed immediately the level of dependence on the average precipitation per year. Along with an increasing water budget, a preference for long term crop rotations, with spring wheat or spring barley being sown following a fallow year, was repeated between two and four times (Baraev 1976). Fallow thus became predominantly a water storage measure and hence used as so-called "black fallow" (three times tillage: flat – flat – deep). Yet, during the last years of the Soviet Union and after its collapse, this method was hardly used at all. Instead methods extremely damaging to the soils and to yields were applied because of the lack of alternatives due to the shortage of herbicides, fertilizers and technology, as well as the shortsighted profit-orientation of the farmers. Key features of the system were:

- Very frequent ploughing even in dry steppe areas
- Burning of straw in situ in the fields on large scale
- Inadequate fallow quality
- Market influenced crop rotations
- Lack of maintenance of the windbreaks
- Failure to apply preventative measures against erosion and to adopt dry farming methods
- Inappropriate application of fertilizers and herbicides.

Ecological consequences of the reclamation activities

Decline of humus stocks

According to investigations carried out mainly in the Great Plains of

North America, the conversion of steppe to cultivated land leads to an evident loss of humus and hence soil-C within the tilled horizons (BALESDENT et al. 1988; LAL et al. 1995). This decline is, in particular, a result of enhanced mineralization of organic matter due to the change in soil climatic conditions, leading to a higher loss rate of greenhouse relevant CO2 gas (MANN 1986). The reduction of soil-C occurs principally during the first years after cultivation. HOUGHTON (1995) reported a rather fast humus loss within the tilled A-horizon after cultivation, that reaches a steady level once the soils gains its micro-biological equilibrium. The humus losses are quantified with values between 30-50 % of the original natural contents (BURKE et al. 1989, p. 803). Our findings in the central Kulundasteppe confirm these estimations. Organic matter content of a 50 year repeated investigated site (Kolkhoz Grishkovka) revealed values of 1.7 % corresponding to about 50 % of the natural humus content in Siberian steppe soils *(Fig. 1)*.

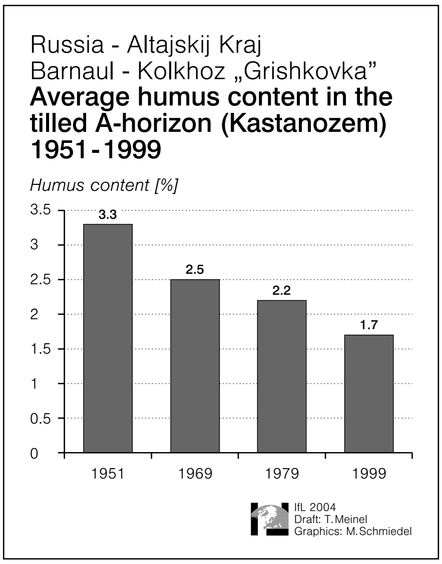

Fig. 1: Average humus content in the tilled A-horizon (Kastanozem) in the Kolkhoz "Grishkovka "
1951 Investigation by the National Land Survey Office of the Altajskij Kraj
1969 Investigation by the Institute "GIPROSEM"/ Barnaul
1979 Investigation by the Institute "GIPROSEM "/ Barnaul
1999 Authors' investigations

Similar severe losses in humus stocks were observed on various sites of the study area comparing natural steppe and cultivated land. Measuring the share of organic material contents in the open forest steppe revealed a similar humus decline as shown for the central steppe. Yet those sites held a higher original humus content of 9.6 % *(Fig. 2)*.

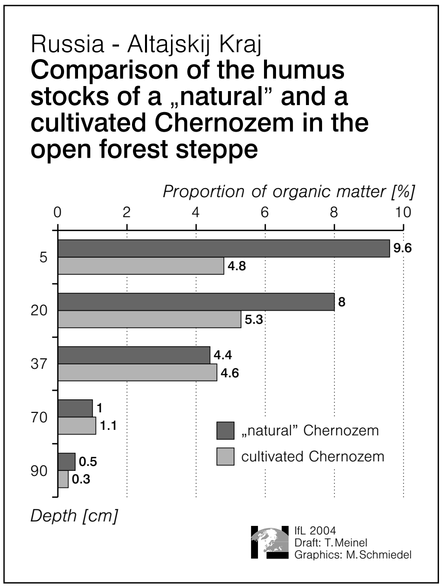

Fig. 2: Comparison of the humus stocks of a "natural" and cultivated Chernozem in the open forest steppe

Part of the humus was already lost directly due to wind erosion following soil tillage (BURKE 1989). The lost material is frequently accumulated at sites near to the fields. These highly dynamic processes lead not only to soil degradation due to denudation or accumulation but also to an increasing differentiation of site-ecological parameters. The further influence of denudation and accumulation on organic matter mineralization is subject of our current investigations.

Wind erosion

First reports about wind erosion events in the Kulundasteppe were published shortly after the site reclamation campaign had started (KOSTROVSKI 1959). Devastating dust storms which lifted the material up to the District capital Barnaul occurred in spring 1957. No information about the affected area or intensity of the soil devastation was given. Other authors observed the loss of certain horizons, especially in soil profiles of the central part of the Kulundasteppe (KALUGIN 1963; BASHENOVA et al. 1997).

BURLAKOVA (1999) reported for the first time about the dimension of the degraded areas. However, this quantification cannot be focused on because it seems difficult to understand that, in 1980, a greater area (900,000 ha) was devastated by water erosion then by wind erosion *(Tab. 2)*. Our geomorphological observations showed that the Kulundasteppe reveals hardly any elevation. BURLAKOVA (1999) points out the evident increase of soil devastation caused by wind erosion, leading to a five time-increase of degraded land between 1980 and 1995.

Year	Area of cultivated land in 1,000 ha	
	Degradation by water erosion	Degradation by wind erosion
1980	900	600
1990	1,300	1,600
1995	1,500	3,000

Tab. 2: Increase in the area of soils degraded by water and wind erosion in the Altaj region
Source: BURLAKOVA 1999, p. 6

Spatial dimension of soil degradation

In order to gain detailed information about form and intensity, and especially about the dimension of degradation caused by water and wind erosion, evaluation of map-based data, of older and current soil inventories and of interviews was carried out. The following three categories for devastation were defined (Land Survey Office of the Altayskiy Kray 1951; Central Archives Altay Kray 1964; Institute "GIPROSEM" 1969/1979):

1. moderate damage (annual loss of soil < 25 m^3 ha^{-1}),
2. medium grade damage (annual loss of soil > 25 m^3 ha^{-1}),
3. heavily devastated land (strong soil degradation leading to a desertification risk).

Category 3 was of special interest for our investigations. Sites classified as category 3 can be characterized by the following attributes:

- Partial or complete denudation of the A-horizon, so that the A-horizon shows currently low humus contents but increased sand share (average ploughing depth of 21 cm),
- High dynamics of sand particles in the soil surface,
- Formation of dunes at the field borders,

• Relatively open vegetation cover in June (partially less than 10 %),
• Frequent soil compressions (plough sole).

The first general results concerning an agriculturally differentiated dimension of the soil degradation was gained by cartographical realization (*Map 4, see supplement B*), revealing the dominance of damage by wind erosion in the Kastanozem region as compared to the Chernozem region. This result can be explained due to the greater soil-specific and climatic exposition to wind erosion of the Kastanozems.

In addition, *Map 4* shows the predominant occurrence of medium grade damaged sites in the open forest steppe area. Yearly average precipitation accounts for about 30 % more than in the central steppe region. Soils are, therefore, less erodable due to the more frequent water availability in the soil. Also, the humus richer Chernozems have a better aggregate stability and thus, are more resistant to drifts. Unlike the dry steppe, the wind protection plants are less damaged in this area and complemented by numerous natural wood enclaves. The average profile shortenings of horizons at these sites were 10 cm in comparison with neighboring natural steppe areas. Therefore, these values are, with respect to their dimension and their temporal development, in accordance with results determined for this region by Russian authors (Atlas Altajskovo Kraja 1978). Remarkably, the humus losses in the zone of the southern Chernozems, reaching values between 30 - 50 % since the reclamation campaign started. Generally, the medium-grade damaged sites reveal the highest area portion in the typical steppe zone and open forest steppe zone of the Kulundasteppe.

Medium-grade damage sites are predominantly found in the zone of the dark, but also in the zone of bright Kastanozems. A clear bottom limit of the ploughed A-horizon at about 20 cm is typical at these sites. On the other hand, the natural dark Kastanozemes of the Kulundasteppe show an average thickness of the Ah-horizon of about 36 cm (Central Archives Altaj-Kraj 1954, indicating a capping of the top soil of at least 15 cm).

The strongest damage classified was observed in the central part of the Kulundasteppe. The bright Kastanozems of this area are predominantly composed of fine sand substrate (the same soil type consisting mainly of silt reveals predominantly grade two damage).

These areas show so much serious soil degradation that the strongest consequences are of the "Dust-Bowl syndrome": Desertification. Many of these sites are not cultivated any more due to the extremely bad yield situation.

Changes of soil properties

Our field and laboratory research and the evaluations of available soil data (Land Surveying Office of the Altay-Kray 1951; Central Archives Altay-Kray 1964, Institute "GIPROSEM" 1969/1979) prove the effect of wind erosion as a cause of the observed (irreversible) soil devastation, leading to yield decline as well as different on- and off-site damages in the study area. The wind erosion effects are extremely polymorph and show high temporal and spatial dynamics. Thus, wind erosion causes great problems compared to water erosion forms regarding the collection and cartographical fixation of data (Hassenpflug 1998). It was rarely possible to differentiate between spatial deflation and accumulation during the field studies. The evidence for deflation events has been complicated because of the homogenizing effect of the annual soil tillage. Soil accumulation could be stated relatively easily due to morphological methods observing dunes next to the streets. Air and satellite images, combined with terrestrial studies, revealed immense information about deflation-derived soil profile shortenings.

The following two examples demonstrate the characteristic effect of wind erosion on the soil:

1. Shortening of the ploughed A-horizon (*Photo 1, see supplement B*)
2. Accumulation in shelter belts and at field borders (*Photo 2, Photo 3, see supplement B*)

The ploughed horizon – especially on exposed sites with deflation – lost not only humic but also erosion-sensible mineral soil. As shown in *Figure 3*, the soil fraction between 0.01 - 0.05 mm (approximately coarse silt according to the German soil classification) is affected in particular. This selective deflation causes a rise of the clay and fine silt fractions as well as of fine sand.

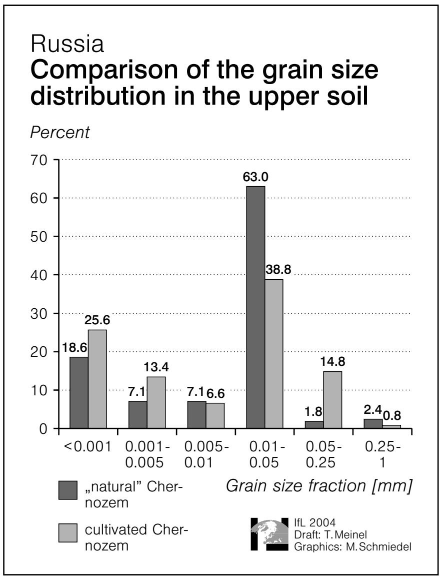

Fig. 3: Selective loss in soil fractions within the ploughed A-horizon of a cultivated Chernozem

Furthermore, under these site-specific dry conditions different (smaller) soil fractions are affected compared to more humid climates, where predominantly fine and middle sand are shifted due to wind erosion (Morgan 1986). Following factors are decisive for this circumstance:

The low precipitation and the relatively high temperature cause strong summer dryness even at a depth up to approx. 7 - 10 cm. This effect is even more pronounced in field profiles. Based on the form and the frequency of the tillage, the drying process is more intensive and further reaching. Even under fallow conditions the soil is tilled to an average depth of 24 cm up to four times a year. Under the relatively dry conditions this procedure forced the destruction of soil aggregates in many cases. An elevated risk of deflation, especially of the coarse silt fraction, is the consequence.

Effects of soil degradation on the yield potential

Resulting from the changes in soil organic matter content, and soil texture caused by land cultivation, fol-

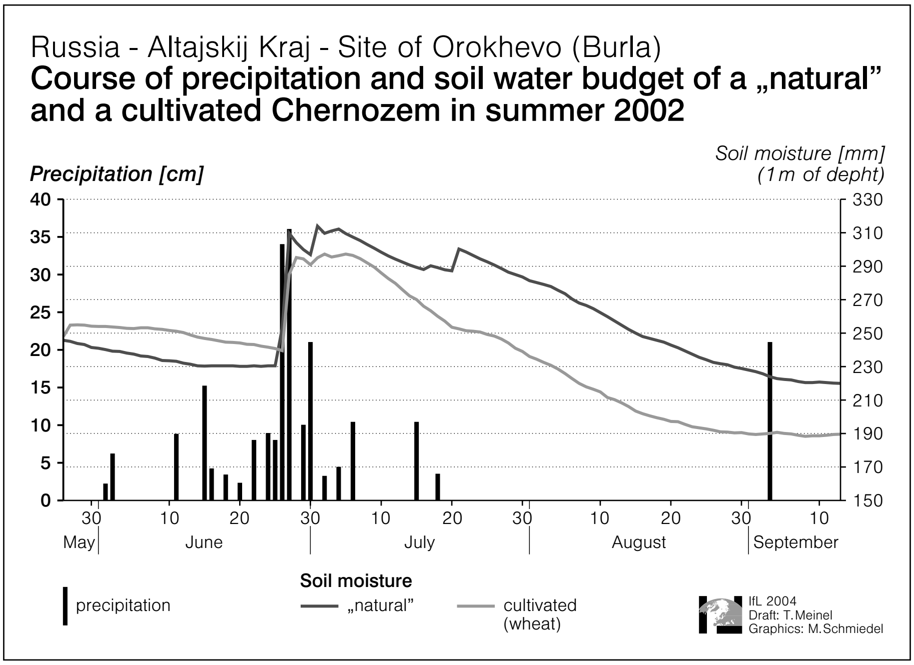

Fig. 4: Soil water budget of a natural and cultivated Chernozem in summer 2002

lowed by erosion events soil (micro-) biological, chemical and physical properties, were influenced permanently.

In particular the humus loss has the most negative consequences for site quality and yield potential. In distinction to the natural sites, the cultivated Chernozems revealed only a medium to low nutrient supply (FINCK 1991). In European agrarian practice a lack of nutrients is usually compensated by fertilizers. This hardly applies to the investigation area where fertilizers have been, due to the resulting costs, very rarely used since the collapse of the former Soviet Union. The application of mineral fertilizers was reduced by 90 % and organic fertilizers by 83 % in the Kulundasteppe since 1990 (STRÖBEL 2000, p. 16). The result is an insufficiency in nutrient supply of soils in the study region.

Our observations and interviews revealed that even in-house fertilizers are hardly used although bullocks and liquid manure are produced on a larger scale. It could not be clearly determined why these bullocks and liquid manure are collected but not brought out to the fields.

Humic substances together with clay minerals form so-called „Clay-Mineral-Complexes", which lead finally to a decline of the soil erodibilty (MORGAN 1998). The loss of organic matter results in an elevated disposition of the affected sites to water and wind erosion.

The loss of organic matter influences the soil-water-budget and its dynamics. In this context, the utilizable field capacity can be discussed as a special parameter (SCHEFFER et al. 1992). Under these site-specific conditions and high organic matter content in the top soil, negative consequences can arise for deep rooting plants such as wheat. A high utilizable field capacity from spring until seeding time is very important for the yield development as it keeps the snow-derived water in the ground and ensures the seeding. On the other hand, a high water budget capacity in the top soil prevents precipitation from reaching deeper soil horizons that are protected against evaporation and thus would be available for a longer time (also with regard to capillary advancement).

The reduction of the silt fraction has similar consequences regarding the yield stability. The selective loss of the finer particles reduces the exchange and water capacity and increases the potential erodibility towards wind erosion (HASSENPFLUG 1998). Particularly in the central part of the Kulundasteppe sites with a higher sand portion in the top soil showed a greater portion of dry damage of the cultivated plants compared to less wind-carved fields. A material transport has already been observed on these degraded sites with rather weak winds.

Yield losses, however, are not only found on deflation-influenced sites, but also on accumulated soils. After an erosion event on May 20th 2000, field observations revealed that on 50 % of the area of the Kolkhoz Grishkovka, the wheat seeding was now covered again up to 10 cm with accumulated soil material. After 7 days the sprouts had died for the most part and had to be ploughed in.

Our data and field observations show that on natural as well as cultivated sites of semi-arid steppe, the available water budget represents the limiting factor for plant growth. Therefore, the collection of data regarding differences on the soil water budget between cultivated and natural steppe sites was of special interest. Different types and grades of degradation had to be investigated comparing natural Kastanozems and Chernozems regarding their specific budget and its dynamics. This was achieved by using the method of soil-moisture-measuring by time domain reflectrometry applied at different soil depths combined with precipitation quantification.

For the first time the soil water dynamics were determined in the south Siberian steppe belt with daily data information at different depths (20, 40, 60 and 80 cm) comparing natural and cultivated sites. The process of freezing in fall and thawing in spring could also be included in the investigation. The measurements were carried out continuously during the complete vegetation period of 2002 and of 2003 *(Fig. 4)*, as well as by parallel recordings of the precipitation in immediate neighborhoods of the investigation plots.

The soil water data reveal the water budget up to 1 m depth (*Fig. 4*). After the thaw, up to the next greater precipitation event, a lower water content was found on the natural sites, overgrown with steppe grasses, than on the cultivated fields. This effect can be explained by the relatively early need of water by the natural grass vegetation. This process begins usually later on the field because the seed time normally covers only in the last ten days of May. Furthermore, the fields are tilled once more right before sowing to ensure weed control. Therefore, the more intensive use of the soil water budget begins only at the end of June on the wheat cultivated sites. There are, however, already very high temperatures at that time so that a lot of water perspires before it can be used by plants. The data show that the natural sites´ water balance is positive compared to the tilled soil. Despite the water supply, the soil water content decreases faster in the cultivated area than in the natural soil. Shortly before harvest time (beginning of September) the water content of the field soil lies about 15 mm under that of the natural site. Despite the differences in the water level, it is interesting to see that both sites reach a steady state, which is not disturbed by heavy rainfall events, as occurred on September 2nd, 2002.

Water erosion

A literature review carried out during the project revealed only the loss of top soil due to water erosion in marginal areas of the study region. DEMIN (1993) refers to a higher water erosion potential in the watershed of the river Kutschuk in the southern steppe. So far no broader knowledge basis exists for the area of the Kulundasteppe. The reason is the low risk potential caused by the relatively flat geomorphological relief. The maximal difference in altitude in the Kulundasteppe is less than 150 m (Atlas Altajskovo Kraja 1978, p. 21). These values are by far lower in the central districts with differences in altitude of 20 - 50 m (DEMIN 1993, p. 43). Therefore, the results of BURLAKOVA (1999, p. 6) reporting a damage by water erosion for 1.5 million acres of arable land (1995), have to be treated very critically as this area represents a tenth of the complete area of arable land for the Altay-Kray (*Tab. 2*).

Our examinations reveal a subordinate importance of water erosion processes in the study area, because hardly any evidence of water erosion could be observed in the whole Kulundasteppe. An exception is the southern part of the study area, the region between Woltschicha and Rodino. Here, we found rill-washing erosion on sites with < 3 ° inclination (*Photo 4, see supplement B*). This form of erosion was found only twice during all of the field studies so that the damage of the rill-washing erosion has to be assessed as rather low in the study area.

Gully erosion can be considered more important and was particularly observed in the catchments area of the river Kutschuk, where the retrogressive erosion of the river carves up the flat upland areas. If the high slopes were cultivated, running erosion appeared at the convex slopes. The role of the tillage of the slopes, or high areas, for the appearance of gully erosion could, so far, not be explained.

However, the following observations are of special interest:

According to the local population, the gully started at numerous sites after 1960 when a water reservoir up the valley was constructed. The base of the receiver and, therefore, the erosion base for the lateral gully erosion were lowered by about 5 m below the dam. The length of an Ovrag, developed only after the dam construction, was 320 m. Hence, as the Ovrag was measured in 2003, the erosion was developing with an average of 7.4 m p. a.

As the lowering of the erosion level represents a special case of erosion, the data of DEMIN (1993, p. 73), regarding the dynamics of the gully erosion and a yearly formation of the Ovrag of 0.3 to 1 m, cannot be compared directly to our own results. In contrast the study of DEMIN (1993) refers to the retrogressive erosion, which he mainly relates to the intensive cultivation of the higher slopes.

In addition to the influence of water erosion, a further example of cultivation-derived influence on gully formation is available. This is gully erosion forced by wind protective forests. Because these shelterbelts are laid out mostly at right angles to the main wind direction, a down slope orientation of the plant rows is often found.

Due to snowdrift accumulation of greater amounts of snow behind the protection plants, the following effects occur. On the one hand, these sites can often only be ploughed and the seed brought out later in the year as the snow needs a longer time to melt and, on the other hand, a water surplus exists here to dampen these places, which also results in seed delays or even makes seeding impossible at these sites (*Photo 5, see supplement B*). In accordance to the location of the wind protection plants, the described water surplus often occurs not only at some spots, but forming stripes on the landscape, where upper soil particles are actually moved with the water as well. As result piping processes are found next to the wind protection stripes. They start with smaller sinking of the top soil and go on along breaking edge towards ravines (*Photo 6, see supplement B*). The 1000 m reaching lengths of the fields is another enhancing factor for these processes. The erosion and landscape destruction is backed up by the nearby deep erosion level as the river Aley runs only 500 m from the field border. The pathway along the valley edge had to be displaced further upslope repeatedly due to the extremely fast head ward erosion.

Feedback of agricultural production

The decline of soil quality properties is also apparent in the long-term yield profile, especially when it is set against the pattern of precipitation since the site reclamation campaign started. The relationship is illustrated here for the Kolkhoz Grishkovka *(Fig. 5)*:

The diagram clarifies the naturally close relation (R^2 = 0.63) between precipitation and yield, showing that the yield is declining when set against a normalized precipitation trend. Considering the improvement of agricultural methods during the past 50 years, this development may be considered even more dramatic. The tendency for declining yields must be mainly attributed to the decline in soil quality. The influence of the political re-organization of the administrative structure since 1990/1991 has to be taken into account. The subsequent reorganizations of the former kolkhoz have so far resulted in only a low financial level of profit. Hence, once the costs of sowing and harvesting have been taken into account, the available financial resources are often used up. Measures for the stabilization or improvement of the soils quality can therefore hardly be undertaken at all.

An analysis of the situation on the scale of the whole Kulundasteppe puts the problem the problem even more sharply into perspective. During

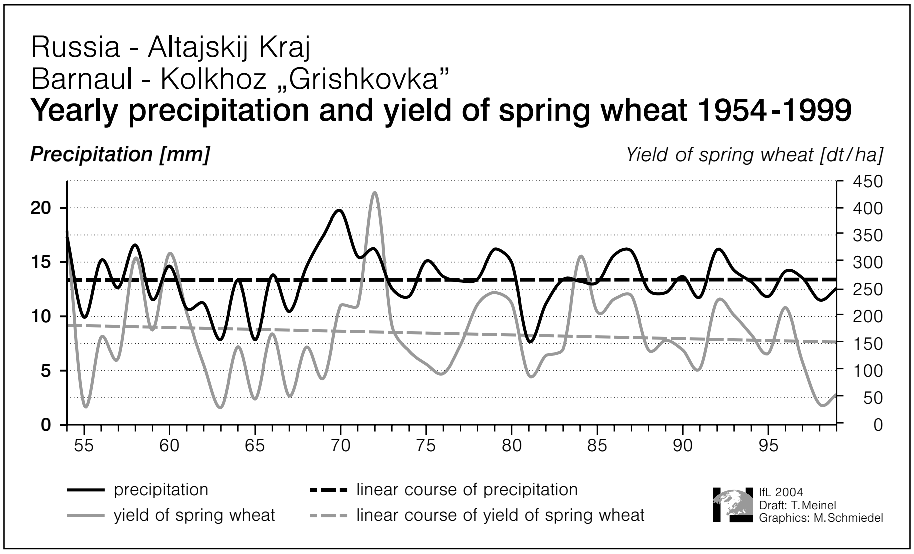

Fig. 5: Yearly precipitations (Kolkhoz Grishkovka) and yield of spring wheat 1954-1999
Sources: Kolkhoz Grishkovka 2000

our investigation, the economic effectiveness of the agriculture in single districts (Rayons) during the past decade was focused on as well. Data from several different economic inspections, carried out by the German Society of Technical Cooperation (GTZ), could be used (STRÖBEL 2000). Results of investigations the variable costs, and the yields, as well as the average sales proceeds per acre were obtained. A break-even point at 500 kg/hectare results from an average variable cost for spring wheat (seeds, labour, mechanization) of 700 rouble/acre and an average sales proceed of 140 rouble/100 kg. This hectare yield must be reached to cover the minimum costs. In this calculation neither taxes nor any possible further financial liability or the investment needs have been included.

The following conclusions can be drawn:

All departments of the central Kulundasteppe, with exception of the department Michailovsky, on average had a loss over the past 10 years (*Map 5, see supplement B*). The situation is particularly dramatic in the departments Uglovsky and Kulundinsky, which in the last decade had operated at a profit in only two years.

Map 5 shows the relation between the economic situation of the company and the site-specific conditions. Unprofitable districts cover the area of the Kastanozem soil type (see map below) with a long-standing average precipitation of some 300 mm p. a. These are also the sites with the strongest soil erosion effects (chapter "Spatial dimension of soil degradation").

From the spatial distribution of the "profitable" economic districts, the economic dry limit can be obtained (SPÄTH 1980). This limit is approximately parallel to the 250 mm precipitation isohyet in the Kulundasteppe area (for the past 10 years).

The 6 districts of the Kulundasteppe have operated at a loss for many years. This raises the question: if there is no economic case, why farm here at all? Furthermore, interviews revealed that most employees in the study region had not been paid for years. They receive sporadic handouts of natural produce, and are usually paid with food parcels for their households.

In conclusion, the "forced" site reclamation campaign has caused various ecological problems, resulting in long-term soil degradation and devastation in the Kulundasteppe during the past 50 years. The reason for these negative effects has to be seen in inadequate cultivation forms combined with site-specific and climatically limiting factors. Another consequence is the declining yield situation at many sites, which are already not profitable. The effects of the reclamation campaign reveal many symptoms of the „Dust Bowl Syndrome".

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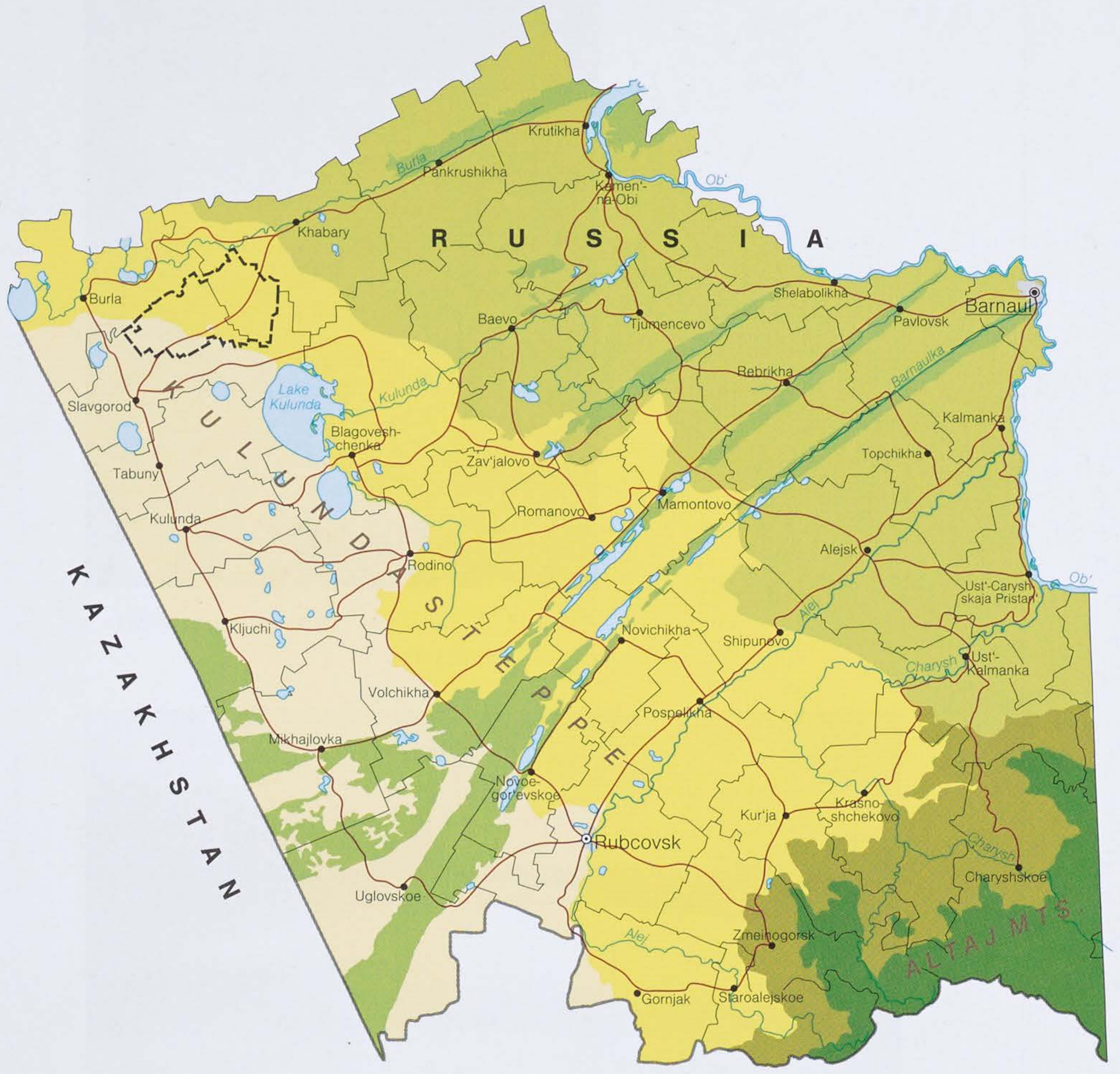
Kulundasteppe - Natural regions



Natural regions
- dry steppe
- steppe
- forest steppe
- interzonal forest
- mountain steppe
- mountain forest

- trunk road
- German National Rayon (GNR)

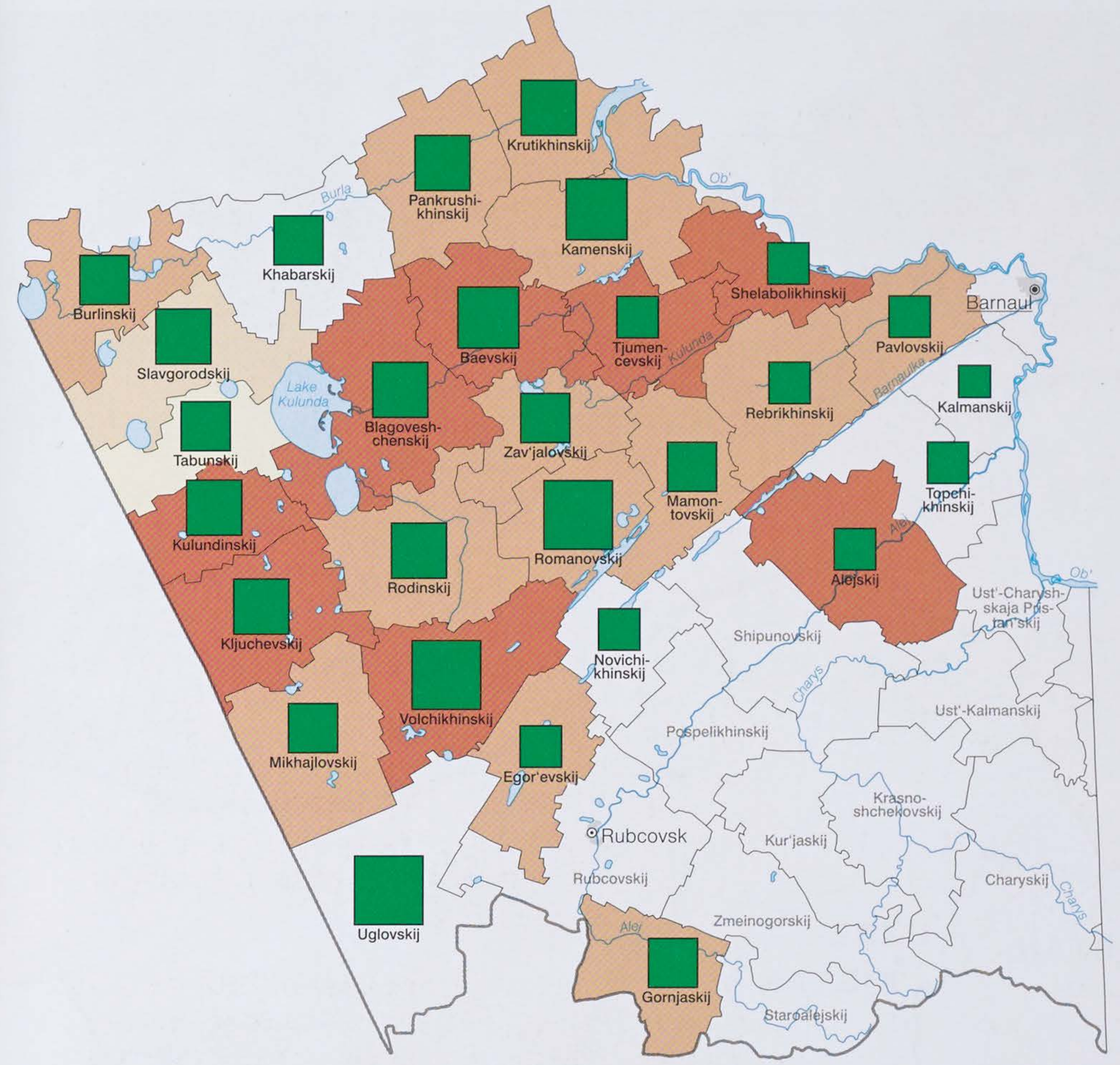
- international boundary
- boundary of rayon

- Barnaul — kraj centre
- Rubcovsk — oblast centre
- Uglovskij — rayon
- Burla — rayon centre
- important city

0 25 50 75 100 km
Scale 1:3250000

Map 2: Natural characteristics of the Kulundasteppe

Kulundasteppe – Increase in arable land during the site reclamation campaign 1953-1955



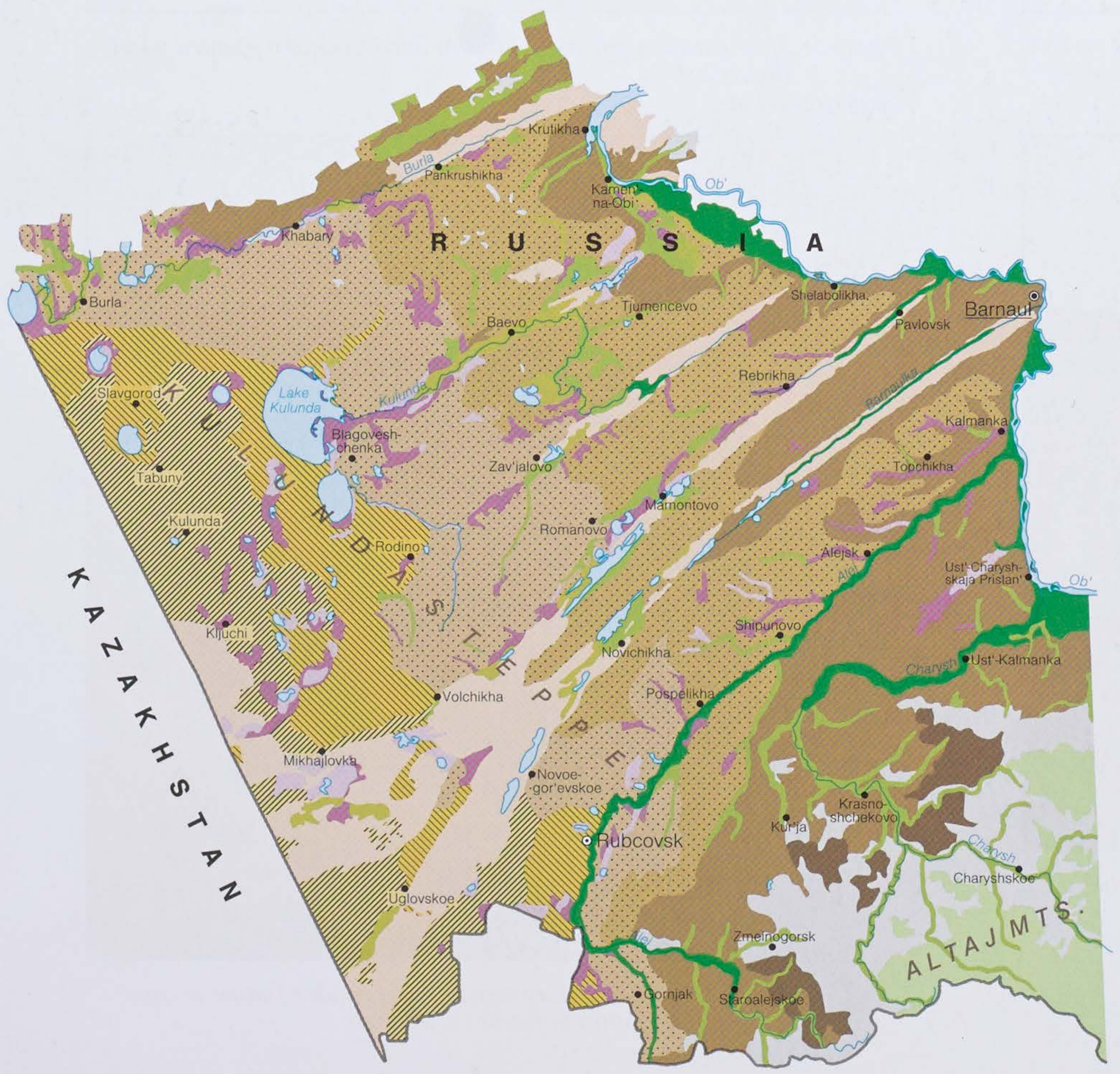
Site reclamation
[1000 ha]
- > 60
- 50 - 60
- 40 - 50
- 30 - 40
- 20 - 30
- < 20
- * no data available

The diagram-scale is equivalent to the map-scale.

Percentage of used arable land in potential arable land
Percent
- > 100
- 98 - 100
- 93 - 98
- < 93
- no data available

Map 3: Distribution of the site reclamation in the Kulundasteppe
Source: Central Archives 1964

Kulundasteppe – Soil types and average degree of soil damage



Soil types
- bright kastanozems
- dark kastanozems
- southern kastanozems
- ordinary chernozems
- typical chernozems
- mountain chernozems

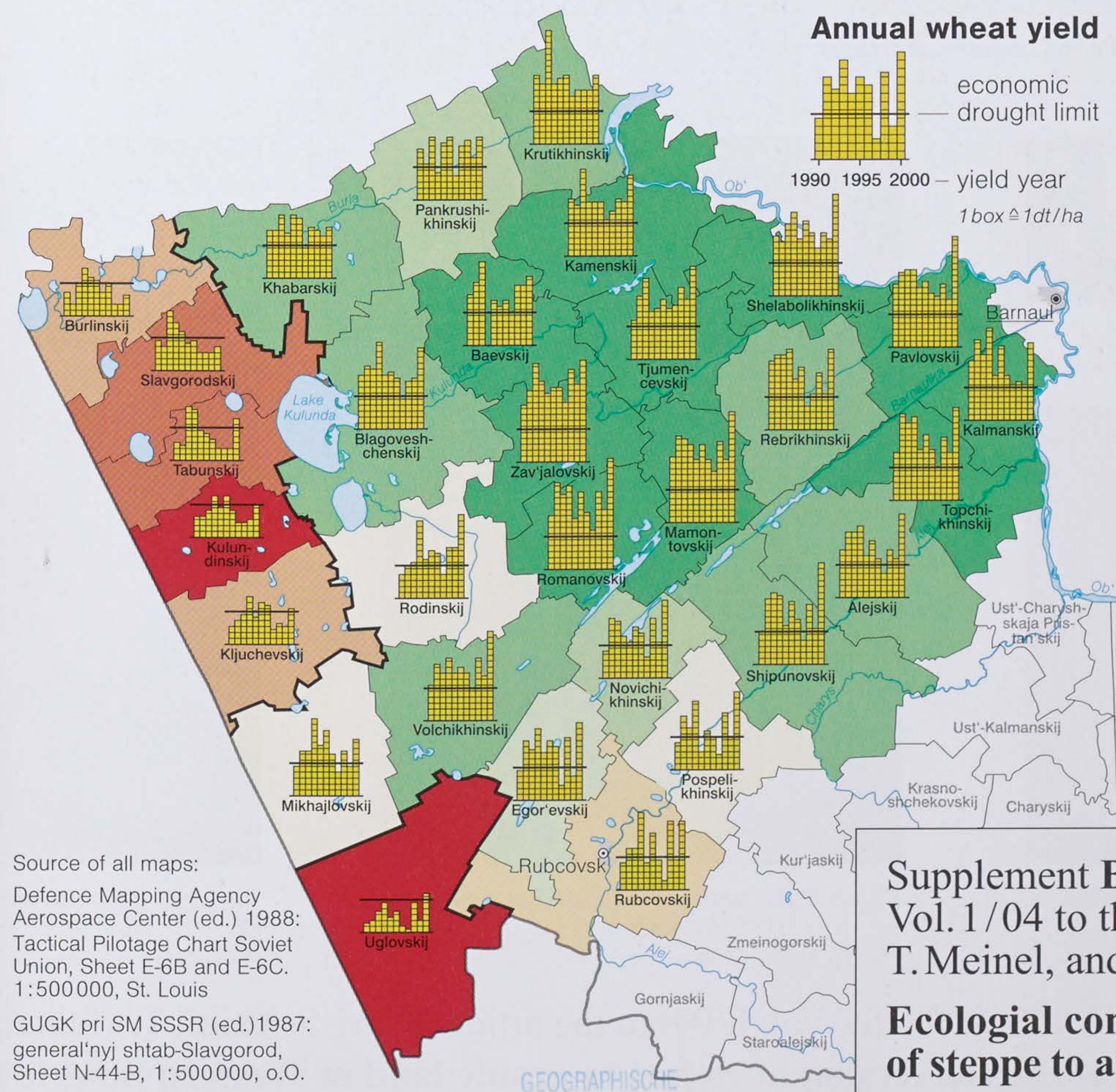
- grey forest soils
- upland meadow soils
- salt meadow soils
- flood-plain soils

- solonchaks
- solonetzes
- flood-plain moors
- loose syrozems

Soil damage
- cat. I (moderate damage)
- cat. II (medium grade damage)
- cat. II 70% cat. III 30% (severe damage)

Map 4: Average degree of soil damage of regions selected with respect to their specific soil types

Kulundasteppe – Economic efficiency of the cultivation of wheat 1990-2000



Annual wheat yield
economic drought limit
1990 1995 2000 – yield year
1 box ≙ 1dt/ha

Number of years of unefficient wheat cultivation 1990-2000
- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- >8
- no data available

economic drought limit (between 5 and 6)

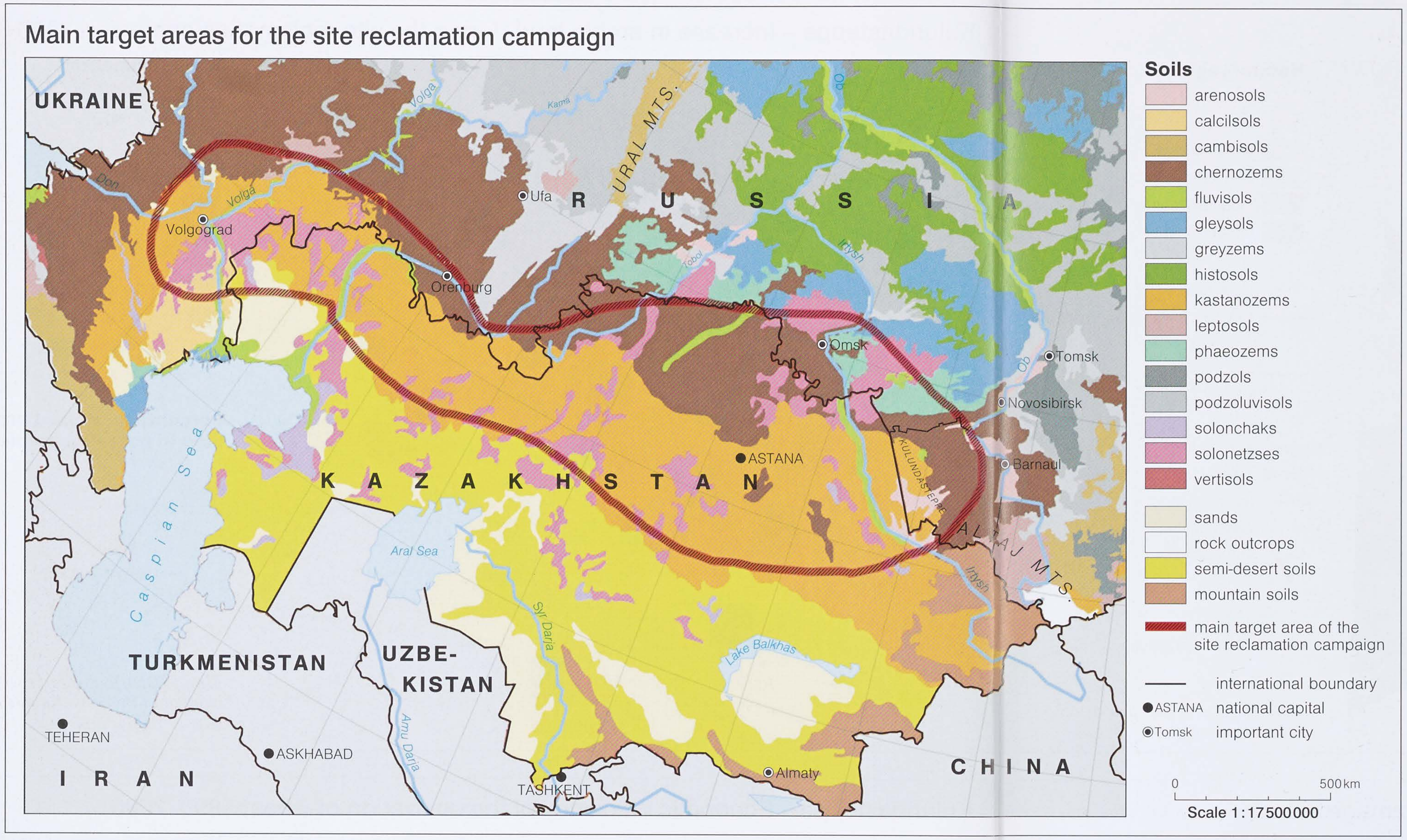
Map 5: Economic situation of the wheat cultivation in the Kulundasteppe

IfL 2004
Cartography: S. Dammann
Adaptation and Layout of the supplement: K. Baum

Source of all maps:
Defence Mapping Agency Aerospace Center (ed.) 1988: Tactical Pilotage Chart Soviet Union, Sheet E-6B and E-6C. 1:500000, St. Louis
GUGK pri SM SSSR (ed.)1987: general'nyj shtab-Slavgorod, Sheet N-44-B, 1:500000, o.O.

Supplement **B** to EUROPA REGIONAL, Vol. 1/04 to the article by M. Frühauf, T. Meinel, and V. Belaev:

Ecologial consequences of the conversion of steppe to arable land in Western Siberia



Map 1: Target areas for the Russian site reclamation campaign

Source: Eule 1962, modified

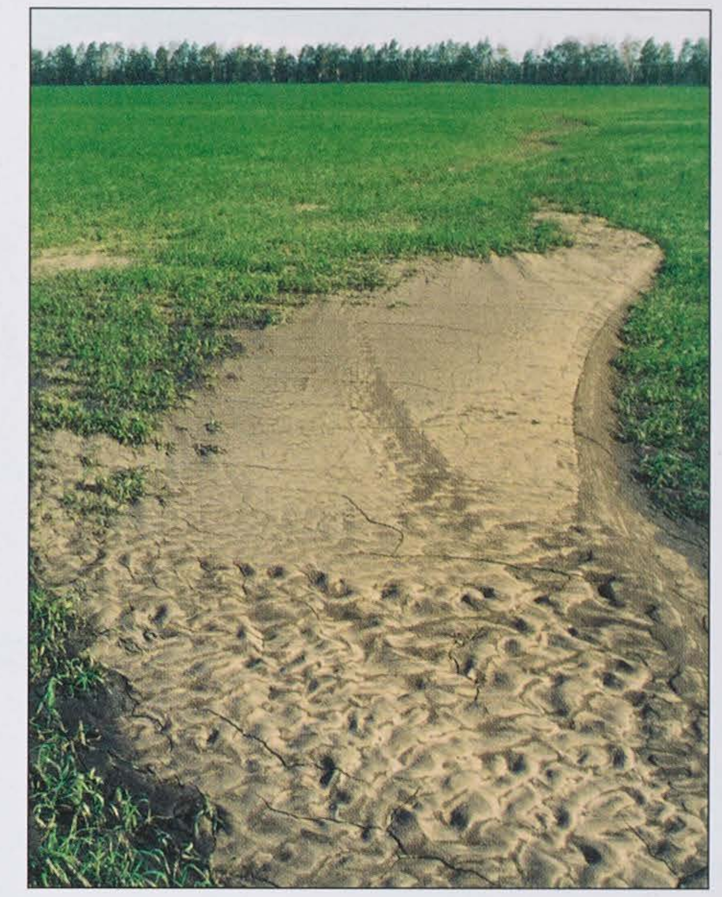


Photo 4: Rill erosion (accumulation area)
Photo: T. Meinel 1999

Photo 5: Spring melting of snow accumulated behind a planted wind shelter belt
Photo: T. Meinel 2001

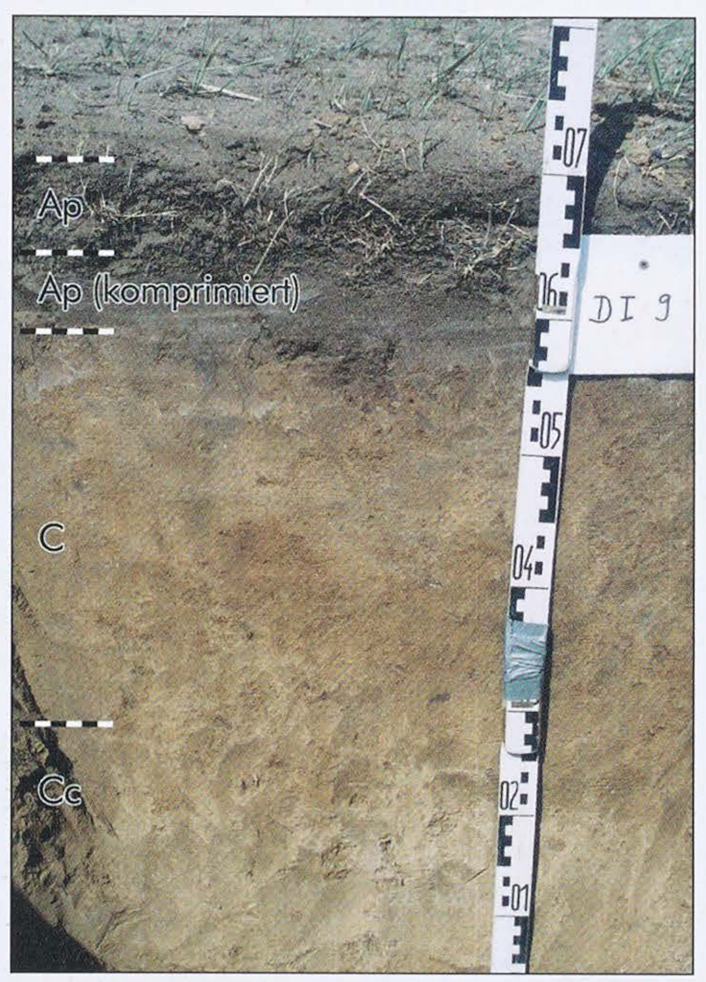


Photo 1: Kastanozem damaged by deflation
Photo: T. Meinel 2000

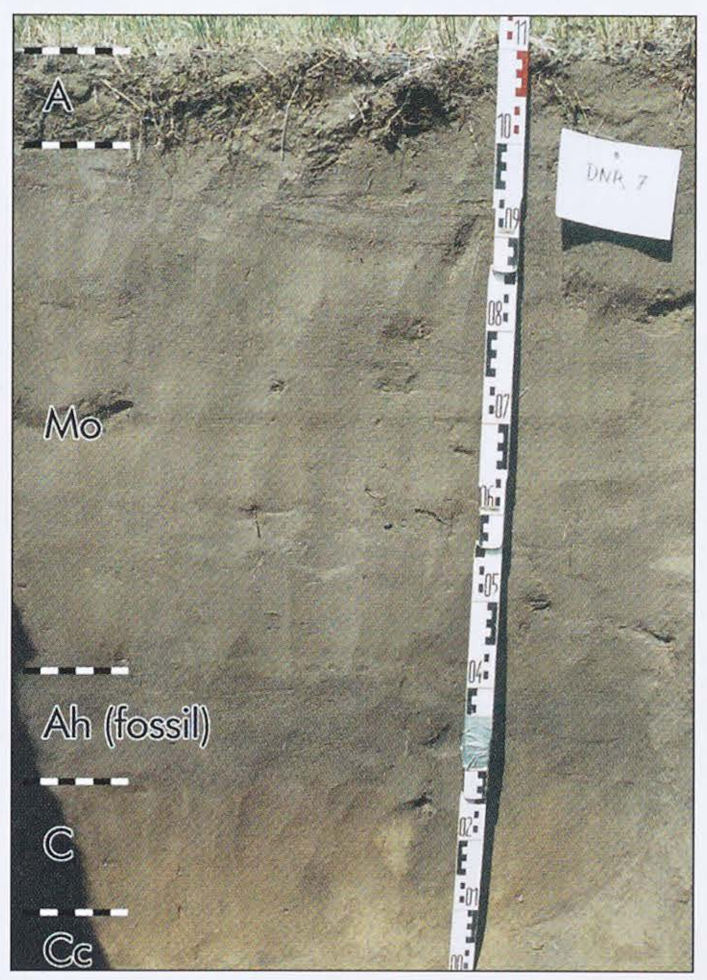


Photo 2: Accumulation of sand in a forest wind shelter belt
Photo: T. Meinel 2000

Photo 3: Accumulation of (medium grain size) sand on a field border after a wind erosion event on 20th May 2000
Photo: T. Meinel 2001

Photo 6: Secondary erosion as a result of snow accumulation at forest shelter belt
Photo: T. Meinel 2003

IfL 2004
Cartography: S. Dammann
Adaptation and Layout of the supplement: K. Baum

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